The Cassini Travel Guide

to Cassini's Second Flyby of Venus

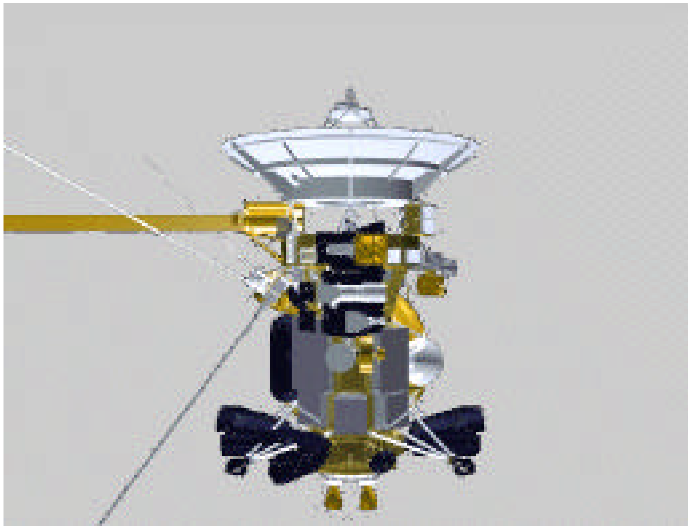


Figure 1. The Cassini Spacecraft

You are there

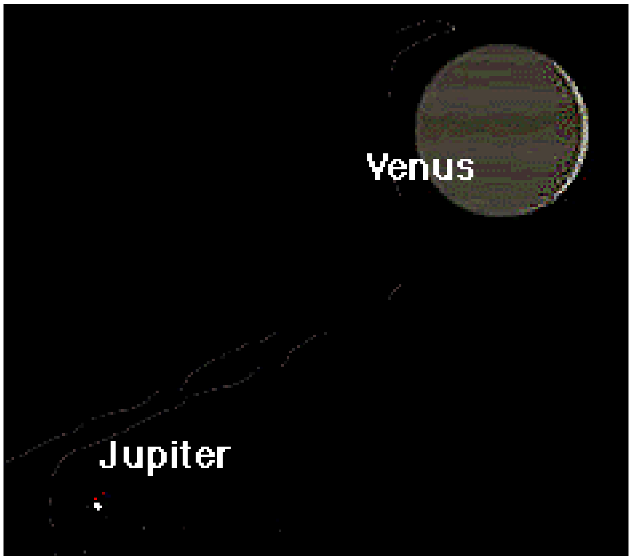
Picture in your mind's eye: it's June, 1999, and you are right there, beside the Cassini spacecraft hanging weightless, following its trajectory deep in interplanetary space (never mind the hostile environment preventing you from really being there). Cassini's launch is years behind. There's no sense of movement, and the two-story-tall spacecraft just seems to be quiet and motionless, except for a quick flash now from of one of the small rocket thrusters on booms near the aft end. A flash repeats once every few hours, to keep the massive robot pointed in the right direction.

You notice a decorated pocket on one side of the spacecraft. It contains the signatures of over six hundred thousand people. Yours is among them, if you sent it by the deadline late in 1997.

There's no planet nearby; nothing to give any hint of Cassini's tremendous velocity. There is only the quiet ocean of space: nothingness in most directions, punctuated by thousands of tiny bright stars, looking like the bright points of light you see on the clearest, darkest nights on Earth. But from here beside Cassini they're clearer, brighter, and never twinkling. Our local star the Sun dominates the scene in one direction, although when you shade it from view the starry darkness returns. The sunlight is hot, so the spacecraft keeps its big, white dish antenna pointed right at it. The resulting shade protects the rest of the craft from overheating. Onboard heaters and blankets are sufficient to prevent freeze damage in the cold shadow.

The sensation is that of falling, yet there is no “up” from which you are falling, nor any “down” you’re falling toward. Oddly, even when Cassini increases its speed as the result of a “gravity assist” planet flyby, there’s no sense of acceleration at all.

One of the many thousands of points of light surrounding Cassini is our home planet -- Earth. The radio signals Cassini constantly transmits are received there, when busy tracking schedules permit. And on that tiny bluish dot, engineers and scientists work on plans for Cassini’s future activities. Radioed commands arrive at Cassini’s antenna, invisibly, silently. They are recognized, processed, stored, silently aboard. As Cassini’s counting clock arrives at times that match certain commands, they execute, most of them unnoticeably from beside the spacecraft. But once in a while there’s some visible activity. When the Magnetometer Boom Deployment commands execute, from your imaginary perspective near Cassini you’ll see the springy boom unravel from its meter-long cannister, within minutes extending to an uncanny 11 meters, holding sensitive field sensing instruments away from magnetic noise generated by the spacecraft. This deployment occurs before Earth flyby, so the magnetometers can be calibrated against the well-known field which shields life on Earth against particles from its parent star.



At first, Venus isn't very convenient to see from beside Cassini: it appears to be very close to the Sun. On June 6 it is *directly* between Cassini and the Sun, with only the planet's far side illuminated: you're approaching Venus from its night side. By early morning on June 23, Venus appears the size of the Moon, from Cassini, and bright Jupiter is close to it in the sky. Venus is a very thin crescent in its "new" phase, but growing larger and larger by the hour: now your tremendous velocity is beginning to show. If you hold up your hand to shield the Sun and the bright crescent Venus, you'll see the background stars appear to be moving relative to the planet, faster and faster, as this Earth-size world approaches. Late the next day, the lifeless world has grown to dominate the scene, much as the blue Earth looms close to astronauts aboard Mir or the Space Shuttle. As you recede from closest approach, Venus shrinks back down to the size of the Moon again by 8 am on June 26, but this time it's extremely bright: you're looking at more than half its illuminated face, and Venus' clouds make it ten times brighter than the Moon could ever be.

Looking away from Venus on the fourth of July, you can see your new target as bright as the Evening star, with the Moon visible near it. At 5 am August 17, Earth is as big as a Full Moon, but it's five times as bright! The next day the home planet fleetingly dominates the scene, only to fall away forever as you sail on into the outer solar system. Following these encounters with Venus and Earth, there won't be much change in scenery until around winter solstice of 2000 when Jupiter will have grown to the size of a full Moon just before flyby.

We invite you to come along on this fascinating flight. Since you can't actually fly along with the spacecraft, we'll try and help in every way to make sure you're as involved as you can be. It's a journey we hope you'll enjoy.

Some Background on Cassini

Cassini's Objectives

The Cassini Mission is designed to carry out a detailed study of Saturn, its atmosphere, its rings, its magnetosphere, its icy satellites, and its largest satellite Titan. The Cassini Orbiter will carry the Huygens Probe into orbit around Saturn in 2004, and then will release it, to enter the dense, hazy atmosphere of Titan. Cassini will continue to orbit Saturn, gathering data for at least four years.

Launch

Cassini's seven-year journey to the ringed planet Saturn began at 4:43 am EDT with the flawless liftoff of its Titan IVB / Centaur from Cape Canaveral, Florida, carrying the Cassini Orbiter and its attached Huygens Probe. The relatively few minutes of Cassini's launch period supplied virtually all the propulsive power needed for Cassini's flight. The spacecraft will be free-falling for all of its nearly seven year cruise, except for some infrequent, small propulsive maneuvers (Trajectory Correction Maneuvers or TCMs) which make tiny adjustments in course or speed.

Cassini's Trajectory

Cassini's launch vehicle didn't speed it on its way toward Saturn, it slowed it down! Before launch, Cassini was, of course, orbiting the Sun, just as you and I are right now. The Titan-IV launch and the first firing of its Centaur upper stage simply separated Cassini from the Earth. It still had the same momentum going around the Sun that it had while still attached by gravity to Earth's surface. Then the Centaur fired again, slowing down the spacecraft, so that it would begin to lag a little behind Earth in its travel around the Sun. The amount of slowing given to Cassini was just enough so that as it continued around the Sun, it would fall in about as far as the orbit of Venus.

Why does Cassini fly by Venus and Earth?

Cassini's flight path was chosen to orbit the Sun twice before heading into the outer solar system. By flying close behind Venus and Earth in their travel around the Sun, Cassini exchanged momentum with these planets. This results in enough added momentum for Cassini to leave the inner solar system, eventually to reach Saturn in 2004. Cassini will also fly behind Jupiter as it orbits the Sun. The added velocity obtained for Cassini, by doing this, shaves over two years from its flight time between Jupiter and Saturn.

Gravity Assist

How can gravity assist a spacecraft? Let's follow Cassini's flight path in the Trajectory diagram, Figure 2. From **point 1** notice Cassini's arc drops inward toward the Sun slightly.

This is the result of the second firing of the Centaur upper stage on the morning of launch. It slowed the spacecraft down a bit, compared with Earth's velocity around the Sun.

At point 2, Cassini flies behind Venus. The planet, of course pulls the spacecraft with its gravity. But the spacecraft has gravity too, and pulls on the planet a minute amount! This causes Venus to lose a little energy from its solar orbit, while Cassini gains a lot. The resulting arc extends out past the orbit of Mars (Mars's orbit is not depicted). You can think of it as a ping-pong ball hitting an electric fan. The fan blades, whirling around the motor, have lots of angular momentum (as do the planets as they go around the Sun). When the ping-pong ball hits a fan blade, it slows the blade a very small amount, but the ping-pong ball gains lots of speed from the encounter. The ball connects with the blade mechanically, while a spacecraft connects with a planet via mutual gravitation.

At **point 3**, the spacecraft fires its main rocket engine to target for the next planet flybys. Cassini's path continues to **point 4** in the illustration as it flies behind Venus again. At **point 5**, Cassini steals energy from Earth's solar orbit, and the spacecraft's resulting arc reaches all the way to Saturn. The Jupiter flyby reduces travel time to the ringed planet.

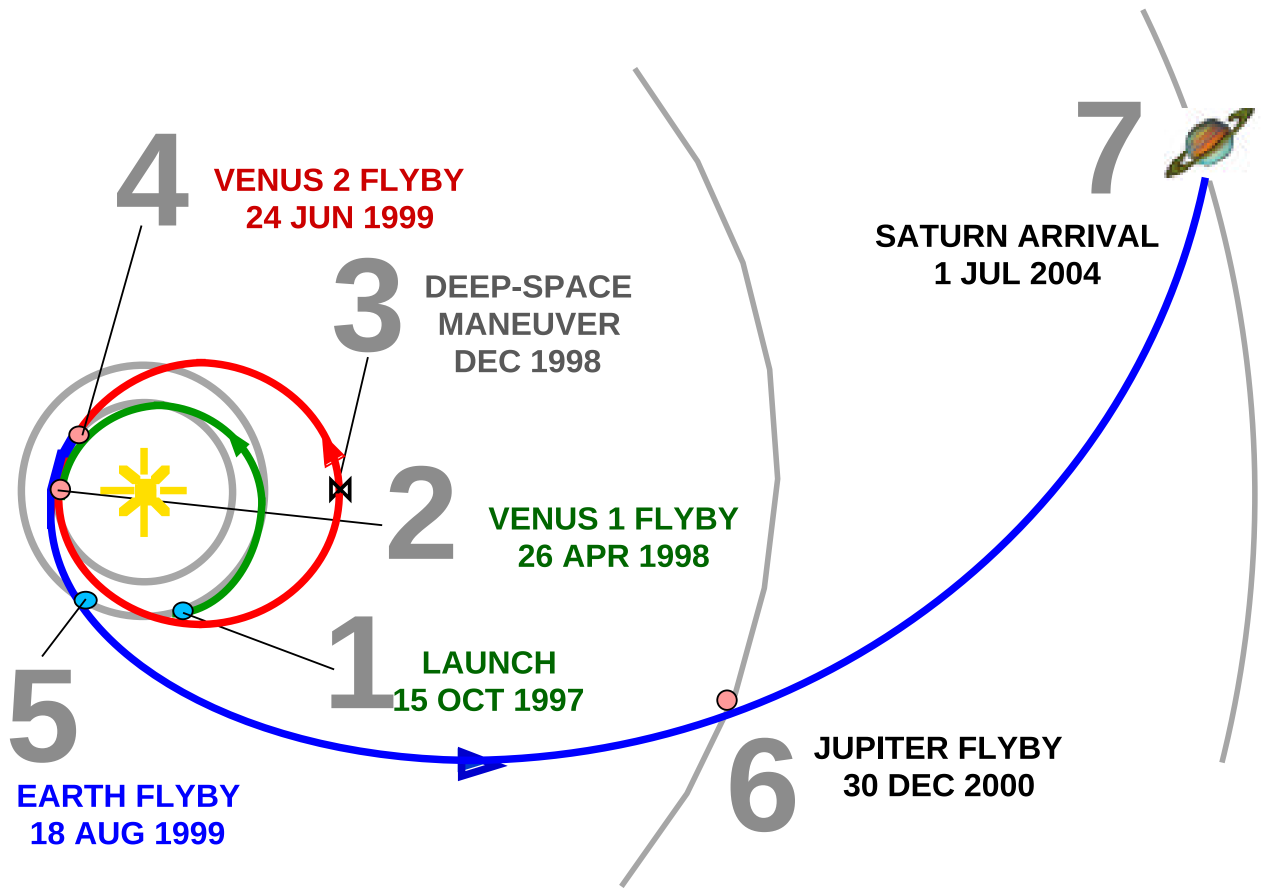


Figure 2. Cassini's Trajectory

The Deep Space Network

Our Long-Distance Company

All robotic interplanetary spacecraft communicate with the engineers and scientists on Earth by means of the Deep Space Network (DSN). The DSN, managed for NASA by JPL, comprises three Deep Space Communications Complexes. One is located in the California desert near Barstow, one is located near Madrid, Spain, and one is near Canberra, Australia, because these places are located about equidistantly around the world. As the Earth turns, at least one complex can “see” a spacecraft at any given time. The DSN’s giant dish antennas are scheduled to track various spacecraft, including Cassini, for the purpose of obtaining tracking data for navigation, telemetry data for science and engineering, radio science data, and sending command data from the flight project to the spacecraft.

Venus Flyby

Timeline of Activities

For a day-to-day description of the activities surrounding the Venus-2 flyby, have a look at Figure 3, the simplified timeline. This timeline was created during the development of the sequence of commands, identified C-14 (Cruise command sequence number 14) which the spacecraft executes over the weeks surrounding the Venus-2 flyby. Dozens of routine background engineering activities and conditions have been removed from the graph, making it easier to see and discuss the ones of major interest. The week numbers along the top refer to the week in 1999. The numbers along the bottom, beginning with 130, indicate the day of year 1999; the L+ numbers in parentheses indicate the number of days since Launch.

The first activity inside the timeline is the Trajectory Correction Maneuver TCM 7 in week 20. At this time, commands uplinked to the spacecraft cause it to turn to the proper attitude and fire the small thrusters for about six minutes. A similar TCM occurs in Week 23. Together, they adjust the exact targeting for flying by Venus. These TCMs, as mentioned, use the small thrusters, known as the Reaction Control System (RCS), rather than the large 400-Newton (100-pound thrust) main engine. The RCS thrusters are rated at less than one Newton each. Four of them fire continuously to provide the small amount of thrust required for an RCS TCM.

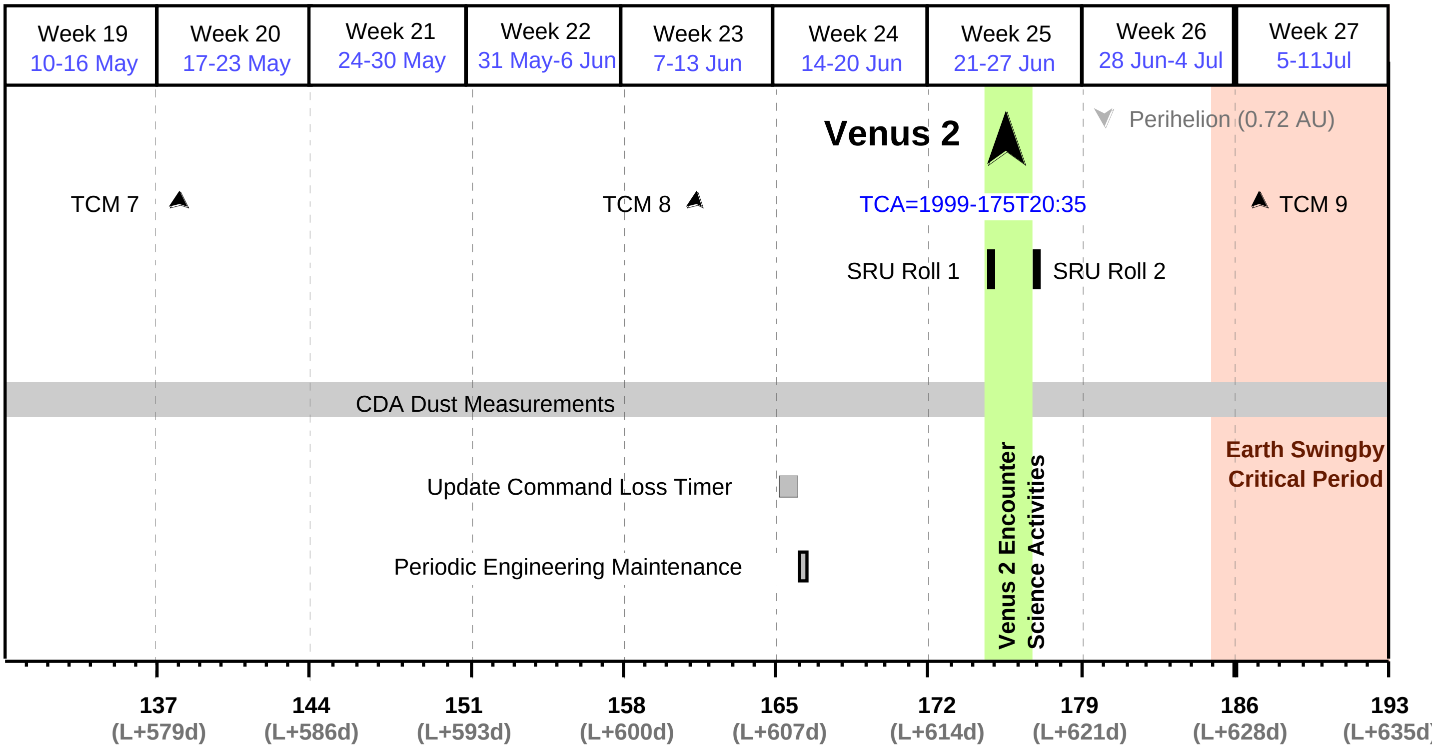


Figure 3. Venus-2 Flyby Simplified Timeline

The RCS thrusters are grouped in clusters at the ends of four struts near the aft end of the spacecraft. These same thrusters are normally used for attitude control, firing individually under control of the onboard computer to keep the spacecraft pointed in the desired direction.

All during this period, as shown in the timeline by the central grey band, the Cosmic Dust Analyzer (CDA) is operating, measuring the number of particles that hit the instrument. This scientific instrument, designed primarily for use at Saturn but operable nearly continuously in cruise, can determine many properties of dust particles, including their direction of travel, mass, and even their chemical composition. Obtaining these measurements in the inner solar system adds to knowledge of the environment. Typically, only a few particles are sensed over a period of several weeks along Cassini's trajectory in the inner solar system.

Below the grey band is an activity to update the Command Loss Timer (CLT). The CLT is a software timer aboard the spacecraft which is reset to a large number of hours every time a command is received from the Earth. If for some reason the spacecraft has not received a command for the number of hours specified (during cruise, this value is typically 264 hours), the spacecraft will autonomously begin taking actions to make sure it has a functioning link to Earth. For example, if one of the receivers on the spacecraft were to fail, it could not receive commands, so it would switch to a spare radio receiver. For periods of high activity levels such as planet flybys, the CLT value is normally reduced, so that in the very unlikely event of a communications failure, recovery of a link to Earth won't take quite so long.

A Periodic Engineering Maintenance (PEM) activity follows. During the PEM, which is scheduled every three months, the main rocket engines exercise their gimbals (the gimbals control the direction the rocket nozzles point). Also, the spacecraft’s reaction wheels are rotated. The reaction wheels are planned to be used for attitude control: if you want to rotate the spacecraft one way, you spin one of its reaction wheels the other way. To rotate the spacecraft back, you slow down the reaction wheel, trading momentum from the wheel back to the whole spacecraft. During cruise in the inner solar system, the wheels are not being used. Rather, for attitude control, the small thrusters fire to maintain proper pointing. The remaining activities during the PEM involve maintenance of data stored in an EEPROM (Electrically Erasable Programmable Read-Only Memory) within the AACS, the Attitude and Articulation Control Subsystem.

At Venus minus six hours the spacecraft rolls, so its Stellar Reference Units (SRU) can provide attitude guidance to the spacecraft without interference from the large, bright planet. Rolling the spacecraft also points the optical science instruments so they can observe Venus. A roll of approximately 40 degrees will place the fields-of-view of the optical remote science instruments in a position to drift across the disk of Venus. The spacecraft will roll back to its nominal cruise attitude approximately 41 hours after closest approach, when the SRU bright body avoidance constraint has ended. These SRU Rolls can be seen bracketing the vertical band labelled “Venus 2 Encounter Science Activities” on the time line. Within this band of time, several of Cassini’s science instruments, besides CDA, are turned on and operated to collect data from Venus and its environment. These include the optical instruments and the fields and particles instruments.

VCA, the time of closest approach to Venus, appears on the timeline in Universal Time, on Day of Year 175. During the following week the spacecraft arrives at Perihelion, its closest point to the Sun in its looping path to Saturn. The next TCM, number 9, serves as a maneuver to “clean up” small residual errors in the trajectory following the planetary flyby. It occurs in the Earth Swingby Critical Period, which lasts from 45 days before, until four hours before Earth closest approach. During this period the Deep Space Network provides extra tracking of Cassini.

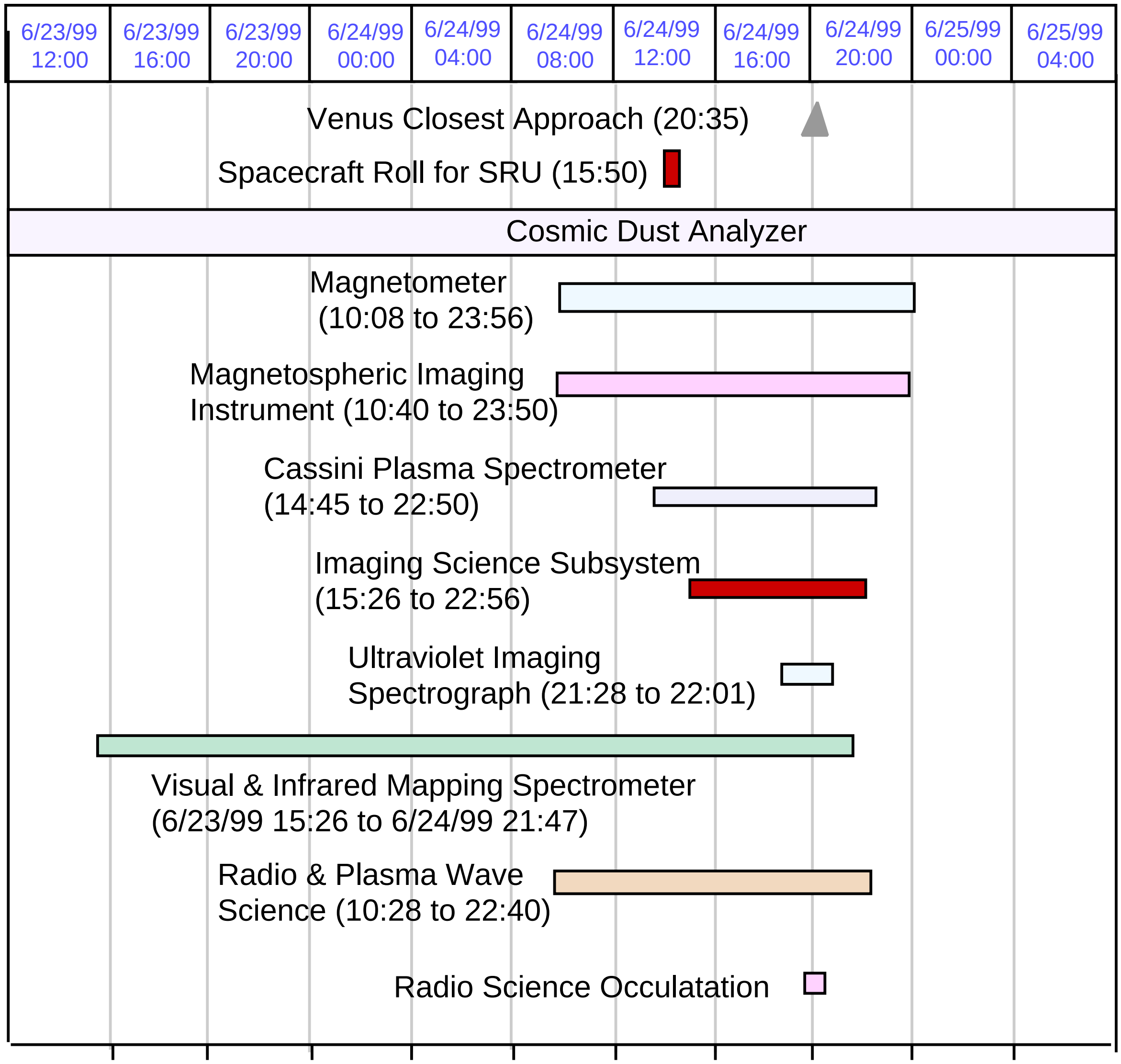


Figure 4. Venus Flyby Instrument Activity TImeline

The Instrument Activity Timeline, Figure 4, illustrates details of the scientific instruments' events. The closest approach, and the spacecraft's first roll appear above the CDA activity already mentioned. Additional instrument activities appear below the CDA line.

MAG, the dual-technique magnetometer, will observe Venus' magnetic field in support of MIMI measurements as the spacecraft plows through the Venusian bowshock, the boundary where the solar wind is first affected by Venus.

MIMI, the Magnetospheric Imaging Instrument, will collect data on the particle population in the spacecraft's immediate environment. Specifically, MIMI will attempt to make insitu ion and electron measurements with LEMMS, its Low Energy Magnetospheric Measuring System, as it flies through the bow shock in the solar wind. It will make measurements of energetic ion mass and charge state with CHEMS, its Charge Energy Mass Spectrometer, and will image the ionosphere, bowshock / solar wind interaction region with its unique instrument, INCA, the Ion and Neutral Camera.

CAPS, the Cassini Plasma Spectrometer, will turn on its Ion Beam Spectrometer (IBS) and its Electron Spectrometer (ELS) about 7 hours before Venus closest approach. Data will be collected from two hours before to one hour after closest approach, to gain more insight into the interaction between Venus and the Solar Wind. Data obtained by MAG will be used to establish particle pitch angles and locations of plasma features, while plasma frequency and Langmuir Probe data from RPWS will augment the CAPS electron measurements.

ISS, the Imaging Science Subsystem, snaps images of the bright cloud tops for the purpose of calibrating the instrument. ISS will take advantage of Venus for “flat-field” calibration of both the Wide-Angle Camera (WAC) and the Narrow-Angle Camera (NAC). The ISS WAC and NAC fields-of-view will come as close as possible to the sub-solar point on the disk of Venus for the most uniform possible illumination. Venus is the only target prior to Titan for in-flight flat field calibration, which is required for observations of Earth, Moon and Jupiter.

UVIS, the UltraViolet Imaging Spectrograph, will be mapping the ultraviolet spectrum of the cloud tops. Using its imaging spectroscopy mode, UVIS will take data as its field of view drifts from the dark side of Venus across the terminator to the bright side. This should provide the highest spectral resolution ever achieved of Venusian airglow, and will help to resolve disagreement between results from UV detectors flown on rocket flights and observations from the Galileo spacecraft when it flew by Venus for its own gravity assist in February 1990.

VIMS, the Visible and Infrared Mapping Spectrometer, will be taking data from deep within Venus' clouded atmosphere. VIMS will use its Visible Channel to gather spectrometer data as it observes atmospheric windows on the night side of Venus. At approximately 20 minutes before closest approach VIMS will scan the limb. Then, about 10 minutes later, VIMS will scan the night side of Venus.
RPWS, the Radio and Plasma Wave Science instrument, will be activated just over eleven hours before Venus closest approach. It will make comprehensive measurements of plasma waves at Venus and extend its search for Venusian lightning, which began at the Venus-1 flyby in April 1998.

Radio Science appears near the bottom of the timeline. Cassini’s Radio Science experiment will be performing an occultation activity during Venus swingby. When Cassini passes behind Venus as seen from Earth, and again as it reappears on the other side, Radio Science will measure the variations in Cassini’s radio signal, such as refraction, scintillation, and attenuation, which are caused by Venus and its atmosphere, to learn more about the atmosphere's composition and structure.

Flight Path

Figure 5 illustrates the Venus flyby geometry. We're looking towards the south, that is down on Venus' northern hemisphere. Note the direction to the Sun: Venus is moving in its orbit toward the lower left. You can see that the spacecraft flies close behind Venus in its path, thus "stealing" momentum from the planet via mutual gravitation. Cassini's closest approach occurs just below Venus' equator, and near 0-degrees longitude. Tick marks are spaced every five minutes along Cassini's flight path. Notice the direction to Earth: Cassini passes behind Venus as seen from Earth, and so will be out of communication for about twenty minutes. All the data from its science observations for this period in "Earth Occultation" will be recorded aboard the spacecraft's solid state recorder and played back later. Cassini never enters into Venus' shadow, or "Sun Occultation" zone.

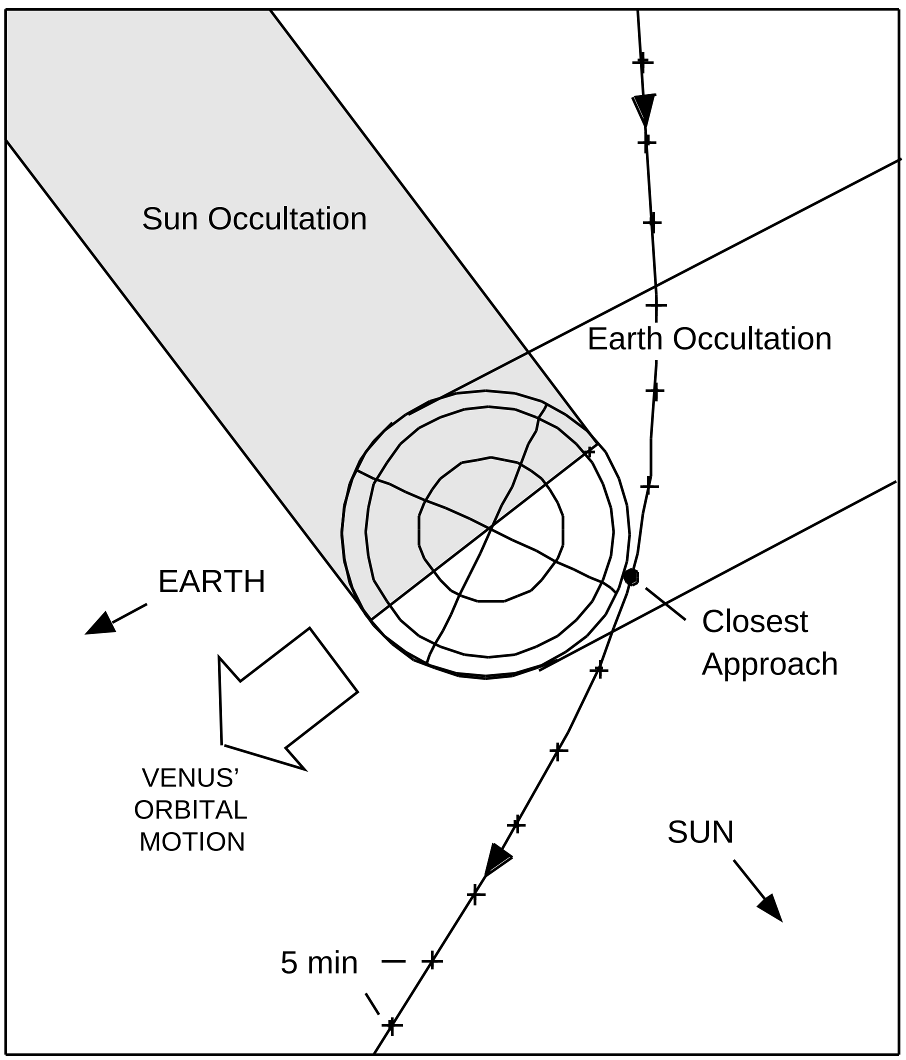


Figure 5. Venus Flyby Geometry

Ground track over Venus

Figure 6 is a view of the surface of Venus, centered on zero degrees longitude, over which the spacecraft passes during the Venus-2 flyby. This image displays radar altimetry data obtained by the Magellan mission in the early 1990s. Low areas are dark, and higher terrain appears lighter. Cassini's flight path and ground track are shown superimposed on the image of Venus' surface. The high spot in the north is the huge volcano Maxwell Mons, in the highland "continent" of Ishtar Terra. Alpha Regio, at 4 degrees east longitude, is the small raised area which is positioned just south of Cassini's flight path.

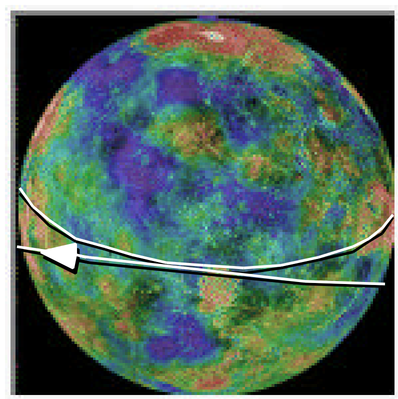


Figure 6. Venus Flight Path and Ground Track

Venus Vitals

Venus is the second planet from the Sun and the sixth largest. Venus' orbit is the most nearly circular of that of any planet, varying less than 1% from perfectly circular.

Orbit:	108,200,000 km (0.72 AU) from Sun
Diameter:	12,103.6 km (95% of Earth's)
Mass:	4.869e24 kg (80% of Earth's)

Venus' rotation is 243 Earth days per Venus day, slightly longer than Venus' year. Its rotation is retrograde, or backwards compared to most other bodies in the solar system. The periods of Venus' rotation and of its orbit are synchronized such that Venus always presents the same face toward Earth whenever the two planets are at their closest.

The pressure of Venus' carbon dioxide atmosphere at the surface is 90 times that of Earth's atmosphere (about the same as the pressure at a depth of 1 km in Earth's oceans). There are several layers of clouds many kilometers thick, composed of sulfuric acid. This dense atmosphere produces a greenhouse effect that keeps the surface temperature over 740K, which is hot enough to melt lead.

On To Jupiter And Saturn

Earth flyby on August 18, 199, provides the final gravity assist for Cassini to reach Saturn (see the Cassini Earth Travel Guide). Planning for science observations has begun for Cassini's flyby of Jupiter on December 30, 2000. Saturn science observations will begin in earnest two years prior to arrival, and will continue in orbit at Saturn for a prime mission of four years. Cassini's initial approach offers the only opportunity to observe the small satellite Phoebe, which orbits in a retrograde direction. Cassini's orbit insertion around Saturn takes it closer than ever to the planet for a unique view of its rings. The first orbit provides an opportunity to release the Huygens Probe to study the atmosphere and surface of Titan.

Some World-Wide Web references

If you have access to the Internet, be sure to join us on this journey to tour the Saturnian system, and to explore related areas. If you don't have internet access at home or at work, you may be able to find access from a public library or university near you.

- Visit the Cassini web site, **http://www.jpl.nasa.gov/cassini**, where all the latest information may be found about the mission's progress, as well as descriptions of the spacecraft, the Huygens Probe, and every aspect of its journey.

- The Solar System Simulator, **http://space.jpl.nasa.gov**, will help you "fly along" with Cassini or to see any solar system body from any other. Be sure to select the view "from the Cassini spacecraft" to see what Cassini is "seeing."

- The Nine Planets, **http://seds.lpl.arizona.edu/billa/tnp**, offers all the latest information about each of the bodies in our solar system.

- The Basics of Space Flight, **http://www.jpl.nasa.gov/basics**, offers a broad overview of the many aspects of interplanetary robotic spaceflight.

Compiled and edited by Dave Doody. Thanks to Steve Edberg, Shannon McConnel, John Aiello, Sharahm Javidnia, Bill Heventhal, Jim Frautnik, Fernando Peralta, Bob Springfield, Dave Seal, and Bill Arnet.